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Abstract

This research effort is concentrated on the computational neuroscience of early vision. Progress was made on the following problems: (i) a model of endstopped visual cortical neurons was extended to include complex components; (ii) an extensive simulation of the model was completed with regard to orientation, positional, spatial frequency, curvature, chevron, and end-line sensitivity; (iii) orientation discontinuities were extended into the motion domain, and psychophysical and computational experiments confirm the hypothesis of multiple directions being represented at a point of discontinuity; and (iv) the mathematical foundations were laid for a theory of shape. Several new projects were also initiated.

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Abstract

This research effort is concentrated on the computational neuroscience of early vision. Progress was made on the following problems: (i) a model of endstopped visual cortical neurons was extended to include complex components; (ii) an extensive simulation of the model was completed with regard to orientation, positional, spatial frequency, curvature, chevron, and end-line sensitivity; (iii) orientation discontinuities were extended into the motion domain, and psychophysical and computational experiments confirm the hypothesis of multiple directions being represented at a point of discontinuity; and (iv) the mathematical foundations were laid for a theory of shape. Several new projects were also initiated.

1. Introduction

Our first year of research support by AFOSR Grant 89-0260 has been an exciting one. Real progress has been made on several fronts, especially Computational Neuroscience, Theory, and Neurophysiology. Several papers have resulted from this research, and we discuss each project in turn.

2. Modeling of Endstopping and Curvature

One of our main area of collaboration continues to be the modeling of endstopped neurons in the visual cortex, with an examination of how well they might respond to curved stimuli. Recall that our model involves a rectified "difference" between the responses of two cells with oriented receptive fields, one large and the other small. We have extended our model to include complex cell components and have completed a very elaborate simulation of it. Questions of spatial frequency response, orientation bandwidth, positional sensitivity, and length sensitivity have been studied in detail. The model makes an enormous number of predictions, which remain to be tested electrophysiologically. The results are described in detail in Appendix 1, which contains a manuscript that has been submitted to the *Journal of Neuroscience*.

3. Motion and MT

We have begun to extend our theoretical efforts into the motion domain, and to extend our modeling efforts into area MT. One of the cornerstones of our conceptual stance has been the treatement of discontinuities in vision, and their separation from points of high curvature. In static scenes this is important for separating bounding contours from occlusions, and analogous results should hold for motion. Physiologically we believe that discontinuities in orientation are represented as multiple neurons firing within a single orientation hypercolumn, and in this study have questioned whether an analagous representation could hold in (coherent, compound) motion. The paradigm was psychophysical, and new displays were designed to confirm it. This project has already resulted in a paper to be published in *Neural Computation*, and the page proofs are included in Appendix II.

4. Toward a Computational Theory of Shape

We view the key bottleneck to high-level vision to be an analysis of shape, and thus have begun to address the question of how to decompose a contour into parts from a theoretical perspective. Exciting mathematical results have been obtained, and will be presented at the first European Conference on Computer Vision later this spring; an overview of the theory is presented in Appendix III.

5. Projects in Progress

5.1 Electrophysiology

In the first year we have made substantial progress on establishing an electrophysiology laboratory at the University of British Columbia. Cynader's ancient PDP-11 computer system has been replaced with an electronic system based on the AT&T Vista boards operating in a MacIntosh II. Using this system we are now able to generate a wide variety of analytic stimuli, including stimuli which vary in location, contrast, spatial frequency, orientation, direction, velocity, and curvature. In addition, we are developing the capacity to create texture patterns which mimic the crucial features of surfaces. These include surface orientation (slant and tilt relative to the observer) and surface curvature. In addition, this system will enable us to generate both monocular and binocular cues associated with locomotion in a three-dimensional environment. Such stimuli should suffice to testing a broad range of predictions from our computational models of curvature and motion selectivity. Particularly interesting will be tests of cortical subunit interactions (described next).

5.2 A Logical/Linear Model Of Cortical Subunit Interaction

In this project we are concerned with modeling the simple cell units that contribute to our curvature models. Several non-linearities have been indicated in the literature, but these have never previously entered formally into modeling; what follows below is an abstract of a poster that will be presented at this year's ARVO (Association for Research in Vision and Ophthalmology) Conference in Sarasota, Florida. The authors are Dobbins, Iverson, and Zucker.

"Visual cortical neurons vary dramatically in their tuning along different stimulus dimensions, and in whether those selectivities are adequately captured by linear models. Certain properties, such as spatial frequency selectivity, seem adequately explained by linear models; while others, such as direction selectivity and endstopping, may involve nonlinearities. We have developed a calculus for the logical combination of local evidence from subunits in which support is accumulated linearly, but incompatible evidence enters nonlinearly. This leads to a class of operators that appears linear for one class of stimuli but markedly nonlinear for others — we call these logical-linear operators. They exhibit dual advantages: they are considerably more stimulus-specific than purely linear operators, while more robust to incidental stimulus variation than logical operators. The viability of such operators as models of visual cortical neurons (e.g. simple cells) is examined by comparing simulations of purely linear and logical-linear models to the responses of cortical neurons. Operators with properties specialised for spatial contours are examined with stimuli

containing vernier offsets, interruptions, and opposite contrast segments. The results are consistent with the well-known "linear" properties (e.g., sensitivity to s.f. gratings) while exhibiting the nonlinear behaviour associated with high vernier sensitivities (Swindale and Cynader, 1989) and strong suppressive effects for opposite contrast segments (Hammond and MacKay, 1983, 1985). Finally, we relate the abstract description of subunit combination to nonlinear synaptic interactions."

5.3 Pharmacological Studies of Co-Circularity and Inter-Columnar Interactions

All of the previous discussion of physiological modeling has concentrated on individual neurons providing local measurements; this project represents the next stage in the hierarchy implemented as inter-columnar interactions. Theoretical modeling by the McGill team, based on the differential goemetry of curves and surfaces, suggests strong curvature-based relationships between nearby orientation (tangent) estimates, and now anatomical investigations by the U.B.C. team are evolving in a consistent direction. In particular, recent research has revealed that connections within the striate cortex are not homogeneous. In fact an individual zone of cortex is connected to a series of nearby *patches* with the cortex. We are examining the specificity of these connections with possible regard to their role in refining initial orientation and curvature estimates provided by local receptive field measurements. We are making many electrode penetrations within the cortex, evaluating physiologic properties at each point, then making HRP injections within the cortex and determining what the properties of the interconnected cells are. Our preliminary results indicate that, in some cases at least, the cortical interconnections favour co-circularity, or the relationships suggested by the theoretical modeling. Although these results are only preliminary, they are sufficently encouraging that we shall pursue this line of investigation much more seriously during the coming year.

6. Supported Personnel

Three graduate students have been supported by this grant: Allan Dobbins (McGill), Lee Iverson (McGill), and Erica Strumpf (U.B.C.).